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(71)出願人 000006828
ワイケイケイ株式会社
東京都千代田区神田和泉町1番地

(71)出願人 591212523
東 健司
大阪府富田林市寺池台3－4－9

(72)発明者 川添 正孝
宮城県仙台市宮城野区枡江9－27

(72)発明者 永洞 純一
宮城県仙台市泉区将監11丁目12－12

(74)代理人 100078994
弁理士 小松 秀岳 （外2名）

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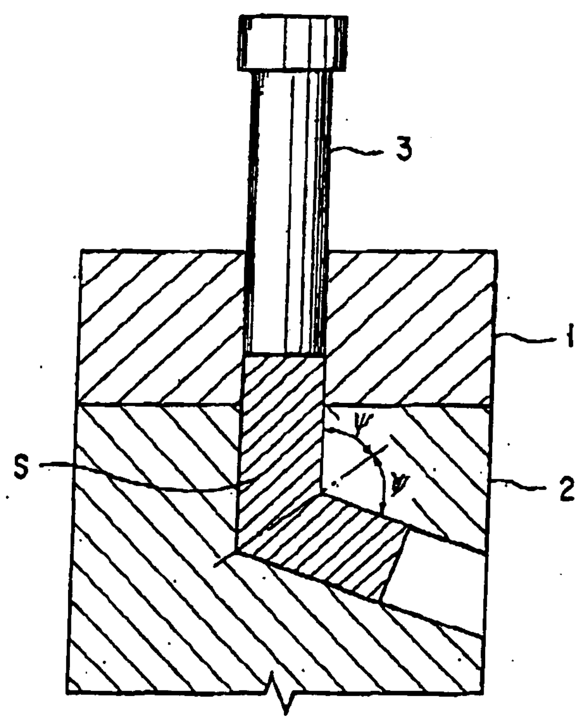
(54)【発明の名称】 マグネシウム合金材の製造方法

(57)【要約】

【課題】 本発明は一回の側方押出でも材料に割れが生ぜず、少ない工程数で結晶粒径の微細化が行え、しかも機械的特性に優れたマグネシウム合金を提供する。

【解決手段】 熱間塑性加工を施したマグネシウム合金材に、２２０％以上の相当伸びに相当する歪量の大きな変形を加え、ミクロ組織の平均結晶粒径を１０μm以下、金属間化合物の平均粒子径を１μm以下に微細化することによって高強度、高靭性材料を製造する。変形加工は素材Ｓの持つ断面積を変化させずにその押出方向を途中で内角（φ）１８０°未満の側方へ変化させる方法あるいは、素材に対して圧力方向を変化させ断面形状を変化させて加圧変形を与える方法によって行う。



【特許請求の範囲】

【請求項１】　熱間塑性加工を施したマグネシウム合金材に、２２０％以上の相当伸びに相当する歪量の大きな変形を加え、ミクロ組織の平均結晶粒径を１０μm以下、金属間化合物の平均粒子径を１μm以下に微細化することによって高強度、高靭性材料を製造することを特徴とするマグネシウム合金材の製造方法。

【請求項２】　マグネシウム合金材が鋳造により作製されたものであり、熱間塑性加工により鋳造組織を破壊する請求項１記載のマグネシウム合金材の製造方法。

【請求項３】　マグネシウム合金材に、その素材の持つ断面積を変化させずに、その押出方向を途中で内角１８０°未満の側方に変化させて剪断応力を与えることによって、２２０％以上の相当伸びに相当する大きな歪を加え、ミクロ組織の平均結晶粒径を１０μm以下、金属間化合物の平均粒子径を１μm以下に微細化し、高強度、高靭性材料を製造する請求項１記載のマグネシウム合金材の製造方法。

【請求項４】　マグネシウム合金材に、その素材に対して圧力方向を変化させ断面形状を変化させて加圧変形を与えることによって、２２０％以上の相当伸びに相当する大きな歪を加え、ミクロ組織の平均結晶粒径を１０μm以下、金属間化合物の平均粒子径を１μm以下に微細化することによって高強度、高靭性材料を製造する請求項１記載のマグネシウム合金材の製造方法。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】本発明は、マグネシウム合金材の製造方法に関し、より具体的には、塑性変形によって高強度、高靭性材料を製造する方法に関する。

【０００２】

【従来の技術】一般に金属又は合金の延性は、高温になればなる程大きくなり、成形加工し易くなる。しかしながら、金属又は合金が高温にさらされると、その機械的特性（強度、硬度等）が低下するという問題がある。一方、機械的特性が低下しない温度では変形能が１００％以下と小さくなり、成形加工し難くなる。また、金属や合金の結晶粒径を小さくし、温度、変形速度などの条件が適切に設定された場合、超塑性変形領域が発現することが知られている。そこで、結晶粒径を小さくし、超塑性変形可能とするために、種々のプロセスが研究されており、例えば、以下のようなプロセスで組織の微細化が行われている。

【０００３】（ａ）鋳造材の場合、第３元素として一般に遷移元素（Mn，Cr，Zr，Ti等）を添加して微細なピンニング粒子を析出させ、熱間加工等での結晶粒の粗大化を防ぐ。

【０００４】（ｂ）急冷凝固法やメカニカルアロイングによって微細組織を有する粉末を作製し、固化する。急冷凝固法の場合、遷移元素を最大固溶限以上まで固溶できるので、鋳造冶金法に比べて微細な粒子が高密度に析出し、一方、メカニカルアロイングの場合、微細な酸化物を高密度に分散させた組織が得られ、これらの微細粒子によって結晶粒の粗大化を防いでいる。

【０００５】前記（ａ）の第３元素を添加する方法の場合、結晶粒径が１ミクロン程度の微細組織は得られるが、多くの複雑な工程を必要とし、工業レベルでは数ミクロンが微細化の限界であった。また、ピンニング粒子として働いている析出物が割れやボイドの起点となったり、疲労強度や靭性を劣化させることもある。一方、前記（ｂ）の急冷凝固法やメカニカルアロイングによれば結晶粒径が１ミクロン以下の微細組織によることは可能であるが、粉末冶金法であるが故に、多くの工程を必要とし、また長時間に及び、その結果、コストが高くなり、鋳造冶金法に比べて経済性、生産性の点で問題があった。また、ピンニング粒子として働いている析出物が割れやボイドの起点となったり、疲労強度や靭性を劣化させることもある。

【０００６】また、本発明者らは、さきにアルミニウム合金材に側方押出を施し、結晶の微細化を行う技術を開発した。（特開平９－１３７２４４号公報、特開平１０－２５８３３４号公報参照）

【０００７】

【発明が解決しようとする課題】しかしながら、本発明のマグネシウム合金の場合、鋳造にて作製した合金材に上記公報に開示の側方押出方法を適用した場合、一回の側方押出にて、材料に割れ（クラック）が生じ、以後の加工及び成形が行えない、という問題がある。

【０００８】そこで、本発明では、このような問題がなく、少ない工程数で比較的簡単に結晶粒径の微細化が行え、しかも機械的特性に優れたマグネシウム合金材を製造することができる方法を提供することを目的とする。

【０００９】

【課題を解決するための手段】本発明は、熱間塑性加工を施したマグネシウム合金材に、２２０％以上の相当伸びに相当する歪量の大きな変形を加え、ミクロ組織の平均結晶粒径を１０μm以下、金属間化合物の平均粒子径を１μm以下に微細化することによって高強度、高靭性材料を製造することを特徴とするマグネシウム合金材の製造方法である。

【００１０】本発明に適用されるマグネシウム合金としては、例えばMg－Al－Zn（AZ系）合金、Mg－Zn－Zr（ZK系）合金などに適用できるが、これらに限らず、通常のMg合金全てに適用可能である。また、本発明に適用されるMg合金にはSc，Zr，Ti，Cr，Mn，Si，Caの少なくとも１種の元素が５wt％以下で含んでいることが好ましい。Mg合金は鋳造により作製されたものにより効果的である。

【００１１】本発明においては、事前に熱間塑性加工を施すことが重要であるが、その具体的な加工としては、

押出、鍛造などが適用でき、その具体的な温度としては２００～３６０℃で行うことが、鋳造組織の破壊及び結晶粒及び金属間化合物の粗大化を防止する上で有効である。特に前記ＺＫ系合金の場合２００～３２０℃で行うことが好ましい。また、熱間塑性加工を施す前に前記押出温度より高い温度で溶体化処理を施すことが好ましい。

【００１２】さらに、本発明において、２２０％以上の相当伸びに相当する歪量の大きな変形を加えるが、これらの具体的な方法としては、第１にマグネシウム合金材に、その素材の持つ断面積を変化させずに、その押出方向を途中で内角１８０°未満の側方に変化させて剪断応力を与えることによって、２２０％以上の相当伸びに相当する大きな歪を加え、ミクロ組織の平均結晶粒径を１０μｍ以下、金属間化合物の平均粒子径を１μｍ以下に微細化し、高強度、高靭性材料を製造するマグネシウム合金材の製造方法の手法があり、第２にマグネシウム合金材に、その素材に対して圧力方向を変化させ断面形状を変化させて加圧変形を与えることによって、２２０％以上の相当伸びに相当する大きな歪を加え、ミクロ組織の平均結晶粒径を１０μｍ以下、金属間化合物の平均粒子径を１μｍ以下に微細化することによって高強度、高靭性材料を製造するマグネシウム合金材の製造方法の手法がある。

【００１３】第１の手法は、側方押出法であって、生産性、経済性等の点で最も好ましい。本発明による側方押出法は、図１に示すように、内面で同一断面積を持つ２つの押出しコンテナー、又はコンテナー１とダイ２を１８０°未満の適当な角度（２φ）で接合し、一方のコンテナー１にＭｇ合金Ｓを挿入し、ラム３によって次のコンテナー又はダイ２に向けて押出しすることによって、材料に側方方向の剪断変形を加える方法であり、好ましくはこの工程を複数回行う。この方法をＭｇ合金に適用することにより、非常に単純な工程で、しかも断面積を減少させずに、結晶粒が１ミクロン以下に微細化され、しかも従来の加工硬化による強度を上回る強化が出来ると同時に、靭性を大きく改善できる。また、そのプロセスは、鋳造組織、合金成分のマクロ、ミクロ的な偏析の破壊、均質化にも効果を持っており、Ｍｇ合金でも一般に行われている高温・長時間の均質化熱処理を省略することもできる。さらに、たとえダイ２において断面減少をともなっても、その効果は変わらない。

【００１４】本発明の側方押出法でＭｇ合金に加えられる剪断変形量は、２つのコンテナーまたはコンテナーとダイの接合角度によって異なる。一般に、この様な剪断変形による押出し１回当たりの歪量$\Delta\varepsilon_i$は、下記式（１）で与えられる。

【００１５】

【数１】

$$\Delta\varepsilon_i=\frac{2}{\sqrt{3}}\cdot\mathrm{cotan}\,\phi \quad \cdots (1)$$

$$\mathrm{ERR}=\frac{Ao}{A}=\exp(\Delta\varepsilon i) \quad \cdots (2)$$

$$\mathrm{EAR}=\left(1-\frac{1}{\mathrm{ERR}}\right)\times 100 \quad \cdots (3)$$

$$\mathrm{EE}=(\mathrm{ERR}-1)\times 100 \quad \cdots (4)$$

【００１６】（但し、$\Delta\varepsilon_i$は歪量、φは接合内角の１／２、ＥＲＲは加工前後の面積比、Ａｏは加工前の断面積、Ａは加工後の断面積、ＥＡＲは加工前後の相当断面減少率、ＥＥは相当歪（伸びと同義）を表わす。）

即ち、２つのコンテナー又はコンテナとダイの接合の内角が直角（９０°）の場合、１回の側方押出で歪量は１．１５（相当伸び：２２０％）、１２０°の場合、歪量は０．６７（相当伸び：９５％）で与えられる。断面積を同一のまま直角に側方押出しすることによって、圧延による圧下率（断面減少率）６９％に相当する加工を加えることが出来る。

【００１７】上記プロセスを繰り返すことによって、材料の断面積を変えずに材料中に無限に歪を蓄積することが出来る。その繰り返しによって材料に与える積算歪量ε_tは、下記式（５）で与えられる。

【００１８】

【数２】

$$\varepsilon_t=\Delta\varepsilon_i\times N \quad \cdots (5)$$

【００１９】（但し、ε_tは積算歪量、Ｎは押出回数を表わす。）

この繰り返し回数（Ｎ）は、理論的には多いほど良いが、実際には合金によってある回数でその効果に飽和状態が見られる。一般のＭｇ合金では、繰り返し数４回（接合内角が直角の場合、積算歪量：４．６、相当伸び：１００００％）で十分な効果を得ることが出来る。圧延によっても無限に歪を蓄積することが出来るが、その場合、断面積は無限に小さくなり、この点において側方押出法とは対照的である。

【００２０】本発明による側方押出しは、出来るだけ低温で行うことが好ましい。しかしながら、合金の変形抵抗は低温になるほど高く、変形能は低温ほど小さくなる傾向がある。押出し用工具の強度の関係及び健全な押出材を得るために、通常は合金によって異なる適切な温度で行われる。一般的には、３００℃以下、好ましくは合金の再結晶温度以下、さらに好ましくは回復温度以下で行われる。しかし、この再結晶温度、回復温度は、材料に加えられる加工度によって変化する。押出温度は、押出角度によっても異なり、角度が大きくなるほど低温で可能となる。これは、押出力（剪断変形に要するエネルギー）が小さくなることと、材料の変形能による制約が緩くなるからである。

【0021】第２の手法は、図２に示すように、逐次圧縮（押圧）方向を変えて鍛造を行う手法であって、例えばＸ軸方向両側から押圧し圧縮させることにより断面形状を変化させ素材に変形を加え、次にＹ軸方向両側から、さらにはＺ軸方向両側からといったように逐次圧縮変形を与える。この際素材の断面積は変化させない方がより好ましい。この手法においても前述の側方押出法と同様に２２０％あるいはそれ以上の相当伸びに相当する歪量を与えることができるとともに結晶粒及び金属間化合物の微細化が行える。また、鍛造の際の温度も上述の押出温度と同様に適用できる。

【0022】これらの手法により平均結晶粒径が１０μｍ以下、金属間化合物の平均粒子径を１μｍ以下とすることができ、このようなＭｇ合金材は、温度１００～３５０℃、歪速度10^{-5}～$10^{0}S^{-1}$の成形加工条件で種々の形状に成形できる。また、成形に際しては１５０％以上の伸びを示すことから、粒界すべりによる変形と粒内（塑性）変形とにより材料が変形し、超塑性的な変形が生じる。また、微細な金属間化合物が存在していることにより、成形の際に上記のように加熱を行っても、結晶粒の粗大化が抑制され、機械的な特性の低下が生じにくい。なお、超塑性的な成形及び機械的特性を考慮した場合、平均結晶粒径は３μｍ以下であることが好ましくより好ましくは１μｍ以下である。

【0023】

【発明の実施の形態】以下、実施例にもとづき、本発明を具体的に説明する。適用合金としてＺＫ６０（Ｍｇ－６Ｚｎ－０．５Ｚｒｗｔ％）を用い、鋳造によって直径８０ｍｍの丸棒を作製し、得られた丸棒を４９９℃で２時間溶体化処理を施し、これを３００℃、押出比１０で押出加工を行った。得られた押出材について、その組織を調べたところ平均結晶粒径２０μｍの再結晶組織が観察された。

【0024】次にこの押出材を用いて、図１に示す側方押出を行った。側方押出の条件は直角（φ＝４５°）に連結した２つのコンテナー（孔の直径２５ｍｍ）を用い、温度４５３Ｋにて行った。側方押出は８回繰り返し行い、前述の式の積算歪量（ε_t）９．４（相当伸び１０００００００％）の加工を受けさせた。このようにして得られたマグネシウム材はクラックの発生等がなく、市販のＴ５処理材が降伏応力２３０ＭＰａ、伸び５％であるのに対し、降伏応力が３７０ＭＰａ、伸び１０％と優れた機械的特性を有するものであった。

【0025】また、組織を透過電子顕微鏡（ＴＥＭ）像（倍率：３万倍）にて調べてみたところ１μｍ以下の微細な結晶粒であるとともに、金属間化合物の大きさも１μｍ以下であることが、また金属間化合物は結晶粒に対し、微細に分散した組織であることが観察された。

【0026】比較として上記と同様の合金について鋳造によって直径２５ｍｍの丸棒を作製し、得られた丸棒を４９９℃で２時間溶体化処理を施し、これを側方押出した。側方押出の条件は上記と同様である。この場合、１回目の側方押出で、材料にクラックが発生した。

【0027】

【発明の効果】本発明の方法によれば、マグネシウム合金を比較的低温で側方押出しすることによって、ミクロ組織の平均結晶粒径を１０μｍ以下、金属間化合物の平均粒子径を１μｍ以下に微細化し、強度、靭性共に従来のマグネシウム合金材料の値を大幅に改善し、バランスの取れたマグネシウム合金材料を提供することができる。すなわち、高強度、高靭性と共に、高耐食性、高衝撃吸収性を併せ備え、かつ、押出加工、冷間加工等の加工性を向上し、固相域でも射出成形も可能となる。

【図面の簡単な説明】

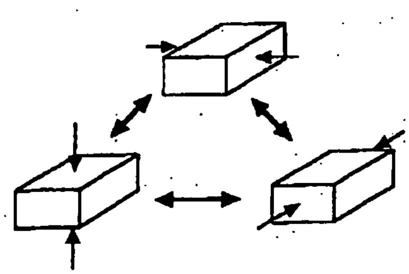
【図１】本発明における側方押出の説明図である。

【図２】本発明において逐次圧縮方向を変えて鍛造を行う方法の説明図である。

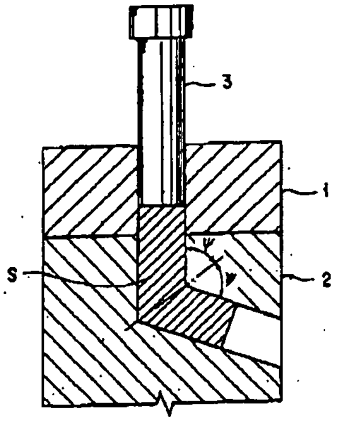
【符号の説明】

1　コンテナー
2　ダイ
3　ラム
5　マグネシウム合金

【図２】



【図１】



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(72)発明者　橋本　貴史
宮城県黒川郡富谷町富ケ丘１－15－22

(72)発明者　東　健司
大阪府富田林市寺池台３－４－９

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(71)Applicant : YKK CORP
AZUMA KENJI

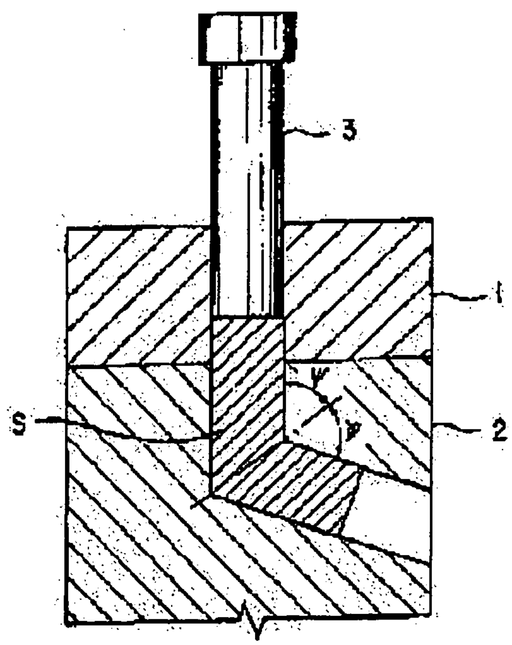
(72)Inventor : KAWAZOE MASATAKA
NAGAHORA JIYUNICHI
HASHIMOTO TAKASHI
AZUMA KENJI

(54) PRODUCTION OF MAGNESIUM ALLOY MATERIAL

(57)Abstract:

PROBLEM TO BE SOLVED: To provide a magnesium alloy material not causing a crack to the material even in one time side extrusion, capable of refining a grain size in a reduced number of processes and excellent in a mechanical property.

SOLUTION: By applying the deformation of a large strain quantity corresponding to ≥220% of equivalent elongation to a magnesium alloy material subjected to hot plastic working and refining an average grain of a micro structure to ≤10 μm and an average grain size of an intermetallic compound to ≤1 μm, a high strength and high toughness material is produced. The plastic working is done by the method to change the extruding direction halfway to a side direction of an interior angle ψ of <180° without changing the cross sectional area of a stock S or the method to impart presssure deformation by changing a pressure direction as well as a cross sectional shape for the stock.



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CLAIMS

[Claim(s)]
[Claim 1] The manufacture approach of the Magnesium alloy material characterized by manufacturing high intensity and a high toughness ingredient by adding big deformation of the deformation amount equivalent to 220% or more of considerable elongation to the Magnesium alloy material which performed plastic working between heat, and making detailed mean particle diameter of 10 micrometers or less and an intermetallic compound to 1 micrometer or less for the diameter of average crystal grain of a microstructure.
[Claim 2] The manufacture approach of Magnesium alloy material according to claim 1 that Magnesium alloy material is produced by casting and destroys cast structure by plastic working between heat.
[Claim 3] The manufacture approach of the Magnesium alloy material according to claim 1 which adds a big distortion which is equivalent to 220% or more of considerable elongation by changing the direction of extrusion to the side of less than 180 degrees of interior angles on the way, and giving shearing stress to Magnesium alloy material, without changing the cross section which the material has, makes detailed mean particle diameter of 10 micrometers or less and an intermetallic compound to 1 micrometer or less for the diameter of average crystal grain of a microstructure, and manufactures high intensity and a high toughness ingredient.
[Claim 4] The manufacture approach of the Magnesium alloy material according to claim 1 which manufactures high intensity and a high toughness ingredient by adding a big distortion which is equivalent to 220% or more of considerable elongation by changing the pressure direction to Magnesium alloy material to the material, changing a cross-section configuration to it, and giving pressurization deformation to it, and making detailed mean particle diameter of 10 micrometers or less and an intermetallic compound to 1 micrometer or less for the diameter of average crystal grain of a microstructure.

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DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Field of the Invention] More specifically, this invention relates to the approach of manufacturing high intensity and a high toughness ingredient by plastic deformation, about the manufacture approach of Magnesium alloy material.
[0002]
[Description of the Prior Art] Generally, the ductility of a metal or an alloy becomes larger, as it becomes an elevated temperature, and becomes easy to carry out fabrication. However, when a metal or an alloy is exposed to an elevated temperature, there is a problem that the mechanical properties (reinforcement, degree of hardness, etc.) fall. On the other hand, deformability becomes small with 100% or less, and stops easily being able to carry out at the temperature to which a mechanical property does not fall for fabrication. Moreover, when the diameter of crystal grain of a metal or an alloy is made small and conditions, such as temperature and deformation velocity, are set up appropriately, it is known that a super-elasticity deformation field will be discovered. Then, in order to make the diameter of crystal grain small and to enable super-plastic deformation, various processes are studied, for example, detailed-ization of an organization is performed in the following processes.
[0003] (a) In the case of a casting, generally add transition elements (Mn, Cr, Zr, Ti, etc.) as the 3rd element, deposit a detailed pinning particle, and prevent big and rough-ization of the crystal grain in hot working etc.
[0004] (b) By the rapid solidification method or mechanical alloying, produce the powder which has a detailed organization and solidify. Since a transition element can be dissolved to more than the maximum solid-solution limit in the case of a rapid solidification method, compared with the casting metallurgical method, the detailed particle deposited in high density, on the other hand, in the case of mechanical alloying, the organization which made high density distribute a detailed oxide was obtained, and these very fine particles have protected big and rough-ization of crystal grain.
[0005] In the case of the approach of adding the 3rd element of the above (a), the detailed organization whose diameter of crystal grain is about 1 micron was obtained, but many complicated processes were needed and several microns were the limitation of detailed-izing on industrial level. Moreover, the sludge which is

working as a pinning particle may serve as an origin of a crack or a void, or fatigue strength and toughness may be degraded. On the other hand, according to the rapid solidification method and mechanical alloying of the above (b), the diameter of crystal grain was able to call at a detailed organization 1 micron or less, but although it was powder-metallurgy processing therefore, many processes were needed, and long duration was attained to, consequently cost became high, and there was a problem in respect of economical efficiency and productivity compared with a casting metallurgical method. Moreover, the sludge which is working as a pinning particle may serve as an origin of a crack or a void, or fatigue strength and toughness may be degraded.

[0006] Moreover, this invention persons gave side extrusion previously to aluminium alloy material, and developed the technique of performing detailed-ization of a crystal. (Refer to JP,9-137244,A and JP,10-258334,A)

[0007]

[Problem(s) to be Solved by the Invention] However, when the side ejector system of an indication in the above-mentioned official report is applied to the alloy produced by casting in the case of the Magnesium alloy of this invention, there is a problem that a crack (crack) arises into an ingredient and future processings and shaping cannot be performed in 1 time of side extrusion.

[0008] So, in this invention, there is such no problem, detailed-ization of the diameter of crystal grain can only be comparatively performed in between by the small routing counter, and it aims at offering the approach that the Magnesium alloy material which was moreover excellent in the mechanical property can be manufactured.

[0009]

[Means for Solving the Problem] This invention is the manufacture approach of the Magnesium alloy material characterized by manufacturing high intensity and a high toughness ingredient by adding big deformation of the deformation amount equivalent to 220% or more of considerable elongation to the Magnesium alloy material which performed plastic working between heat, and making detailed mean particle diameter of 10 micrometers or less and an intermetallic compound to 1 micrometer or less for the diameter of average crystal grain of a microstructure.

[0010] As a Magnesium alloy applied to this invention, although it is applicable to a Mg-aluminum-Zn (AZ system) alloy, a Mg-Zn-Zr (ZK system) alloy, etc., for example, it is applicable not only to these but all the usual Mg alloys. Moreover, it is desirable that at least one sort of elements of Sc, Zr, Ti, Cr, Mn, Si, and calcium contain in Mg alloy applied to this invention less than [5wt%]. Mg alloy is effective by what was produced by casting.

[0011] In this invention, although it is important to perform plastic working between heat in advance, it is effective to be able to apply extrusion, forging, etc. and to carry out at 200-360 degrees C as the concrete temperature as the concrete processing, when preventing big and rough-ization of destruction and crystal grain of cast structure, and an intermetallic compound. It is desirable to carry out at 200-320 degrees C especially in the case of said ZK system alloy. Moreover, before performing plastic working between heat, it is desirable to perform solution treatment at temperature higher than said extrusion temperature.

[0012] Furthermore, although big deformation of the deformation amount equivalent to 220% or more of considerable elongation is added in this invention By changing the direction of extrusion to Magnesium alloy material on the way in the side of less than 180 degrees of interior angles, and giving shearing stress to it as these concrete approaches, the 1st, without changing the cross section which the material has The big distortion equivalent to 220% or more of considerable elongation is added. The diameter of average crystal grain of a microstructure 10 micrometers or less, Mean particle diameter of an intermetallic compound is made detailed to 1 micrometer or less, and there is the technique of the manufacture approach of the Magnesium alloy material which manufactures high intensity and a high toughness ingredient. By changing the pressure direction to Magnesium alloy material to the material, changing a cross-section configuration to the 2nd, and giving pressurization deformation to it The big distortion equivalent to 220% or more of considerable elongation is added, and there is the technique of the manufacture approach of the Magnesium alloy material which manufactures high intensity and a high toughness ingredient by making detailed mean particle diameter of 10 micrometers or less and an intermetallic compound to 1 micrometer or less for the diameter of average crystal grain of a microstructure.

[0013] The 1st technique is a side extrusion method and is the most desirable in respect of productivity, economical efficiency, etc. As shown in drawing 1 , by joining a die 2 to two extrusion containers which have the same cross section inside, or a container 1 at the suitable include angle (2psi) of less than 180 degrees, inserting the Mg alloy S in one container 1, and extruding and carrying out towards a following container or a following die 2 with a ram 3, the side extrusion method by this invention is an approach of adding the shear strain of the direction of the side to an ingredient, and performs this process two or more times preferably. By applying this approach to Mg alloy, it is a very simple process, and crystal grain is made detailed by 1 micron or less, without moreover decreasing the cross section, and toughness is greatly improvable while strengthening exceeding the reinforcement by the conventional work hardening moreover can be performed. Moreover, the process has effectiveness also in cast structure, the macro of an alloy content, destruction of a micro segregation, and homogenization, and hot and prolonged homogenization heat treatment to which Mg alloy is generally also carried out can also be omitted. Furthermore, even if accompanied by cross-section reduction in a die 2, the effectiveness will not change.

[0014] The amount of shear strains applied to Mg alloy with the side extrusion method of this invention changes with junction include angles of two containers or a container, and a die. Generally, deformation amount **epsiloni per extrusion by such shear strain is given by the following formula (1).

[0015]

[Equation 1]

$$\Delta \varepsilon_i = \frac{2}{\sqrt{3}} \cdot \cot \psi \quad \cdots (1)$$

$$ERR = \frac{Ao}{A} = \exp(\Delta \varepsilon i) \quad \cdots (2)$$

$$EAR = \left(1 - \frac{1}{ERR}\right) \times 100 \quad \cdots (3)$$

$$EE = (ERR - 1) \times 100 \quad \cdots (4)$$

[0016] (however, **epsiloni -- a deformation amount and psi -- in the cross section before processing, and A, the cross section after processing and EAR express the considerable reduction of area before and behind processing, and EE expresses [1/2 of a junction interior angle, and ERR / the surface ratio before and behind processing, and Ao] an equivalent strain (elongation and homonymy).) That is, when the interior angle of junction of two containers or a container, and a die is a right angle (90 degrees), a deformation amount is given by 1 time of side extrusion, and, in the case of 1.15 (considerable elongation: 220%) or 120 degrees, a deformation amount is given by 0.67 (considerable elongation: 95%). By carrying out side extrusion of the cross section to a right angle, while it has been the same, processing equivalent to 69% (reduction of area) of rolling reduction by rolling can be added.

[0017] By repeating the above-mentioned process, distortion can be accumulated into an ingredient at infinity, without changing the cross section of an ingredient. Addition deformation amount epsilont given to an ingredient by the repeat is given by the following formula (5).

[0018]

[Equation 2]

$$\varepsilon_t = \Delta \varepsilon_i \times N \quad \cdots (5)$$

[0019] (However, epsilon 1 expresses an addition deformation amount and N expresses the count of extrusion.)

Although many these counts of a repeat (N) are theoretically good so that there are, a saturation state is looked at by that effectiveness by a certain count with an alloy in fact. With common Mg alloy, effectiveness sufficient by four repeat numbers (addition deformation amount: 4.6, considerable elongation when a junction interior angle is a right angle : 10000%) can be acquired. Although distortion can be accumulated in infinity also with rolling, the cross section becomes small in that case at infinity, and it is contrastive with a side extrusion method in this point.

[0020] As for the side extrusion by this invention, it is desirable to carry out at low temperature as much as possible. However, the deformation resistance of an alloy is so high that it becomes low temperature, and deformability has the inclination for low temperature to become small. In order to obtain the strong relation and the strong healthy extruded material of the tool for extrusion, it is carried out at the suitable temperature which usually changes with alloys. Generally, 300 degrees C or less are preferably performed below with recovery temperature still more preferably below the recrystallizing temperature of an alloy.

However, this recrystallizing temperature and recovery temperature change with the workability added to an ingredient. Extrusion temperature changes also with extrusion include angles, and it becomes possible at low temperature, so that an include angle becomes large. This is because constraint by that extrusion force (energy which shear deformation takes) becomes small, and the deformability of an ingredient becomes loose.

[0021] The 2nd technique is the technique of forging by changing the compression (press) direction serially, as shown in drawing 2 , for example, changes a cross-section configuration by making it press and compress from X shaft-orientations both sides, adds deformation to a material, and then, from Y shaft-orientations both sides, as it said further that it was from Z shaft-orientations both sides, it gives a compression set serially. Do not make it under the present circumstances, more more desirable for the cross section of a material to change. While being able to give the deformation amount which is equivalent to the considerable elongation beyond 220% or it like the above-mentioned side extrusion method also in this technique, detailed-ization of crystal grain and an intermetallic compound can be performed. Moreover, the temperature in the case of forging as well as above-mentioned extrusion temperature is applicable.

[0022] The diameter of average crystal grain can set mean particle diameter of 10 micrometers or less and an intermetallic compound to 1 micrometer or less by such technique, and such a Mg alloy can be fabricated in configurations various on the temperature of 100-350 degrees C, and the fabrication conditions of strain rate 10-5-100S-1. Moreover, since 150% or more of elongation is shown on the occasion of shaping, an ingredient deforms according to deformation in deformation by the grain boundary skid, and a grain (plasticity), and super-elasticity-deformation arises. Moreover, when the detailed intermetallic compound exists, even if it heats as mentioned above in the case of shaping, big and rough-ization of crystal grain is controlled, and it is hard to produce the fall of a mechanical property. In addition, when super-elasticity-shaping and a mechanical property are taken into consideration, it is desirable more desirable that it is 3 micrometers or less, and the diameter of average crystal grain is 1 micrometer or less.

[0023]

[Embodiment of the Invention] Hereafter, based on an example, this invention is explained concretely. Using ZK60 (Mg-6Zn-0.5Zrwt%) as an application alloy, by casting, the round bar with a diameter of 80mm was produced, solution treatment was performed for the obtained round bar at 499 degrees C for 2 hours, and extrusion was performed for this with 300 degrees C and an extrusion ratio 10. About the obtained extruded material, when the organization was questioned, it gazed at the recrystallized structure of 20 micrometers of diameters of average crystal grain.

[0024] Next, side extrusion shown in drawing 1 was performed using this extruded material. The conditions of side extrusion were performed in temperature 453K using two containers (diameter of 25mm of a hole) connected with the right angle (psi= 45 degrees). Side extrusion made processing of a repeat deed and the addition deformation amount (epsilont) 9.4 (1 million % of considerable elongation)

of the above-mentioned formula received 8 times. Thus, yield stress was what has the mechanical property in which the obtained magnesium material does not have generating of a crack etc., and it excelled with 370MPa(s) and 10% of elongation to commercial T5 processing material being yield stress 230MPa and 5% of elongation.

[0025] moreover, when a transmission electron microscope (TEM) image (scale factor: 30,000 times) investigates an organization, while being detailed crystal grain 1 micrometer or less, the magnitude of an intermetallic compound is also 1 micrometer or less -- moreover, it was observed that an intermetallic compound is the organization which distributed minutely to crystal grain.

[0026] Solution treatment was performed for the round bar which produced the round bar with a diameter of 25mm by casting, and was obtained at 499 degrees C about the alloy same as a comparison as the above for 2 hours, and side extrusion of this was carried out. The conditions of side extrusion are the same as that of the above. In this case, the crack occurred into the ingredient in the 1st side extrusion.

[0027]

[Effect of the Invention] According to the approach of this invention, by carrying out side extrusion of the Magnesium alloy at low temperature comparatively, mean particle diameter of 10 micrometers or less and an intermetallic compound can be made detailed for the diameter of average crystal grain of a microstructure to 1 micrometer or less, and reinforcement and toughness can offer the Magnesium alloy ingredient with which it has improved sharply and balance was able to take the value of the conventional Magnesium alloy ingredient. That is, it combines and has high corrosion resistance and high impact absorptivity with high intensity and high toughness, and workability, such as extrusion and cold working, is improved, and injection molding also becomes possible also in a solid phase region.

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DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]
[Drawing 1] It is the explanatory view of the side extrusion in this invention.
[Drawing 2] It is the explanatory view of the approach of forging by changing the compression direction serially in this invention.
[Description of Notations]
1 Container
2 Die
3 Ram
5 Magnesium Alloy

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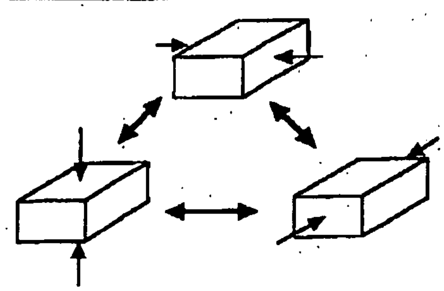
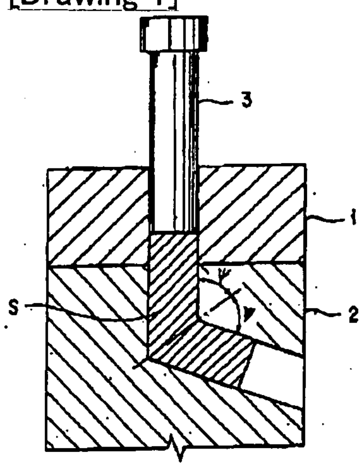
DRAWINGS

[Drawing 2]



[Drawing 1]



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